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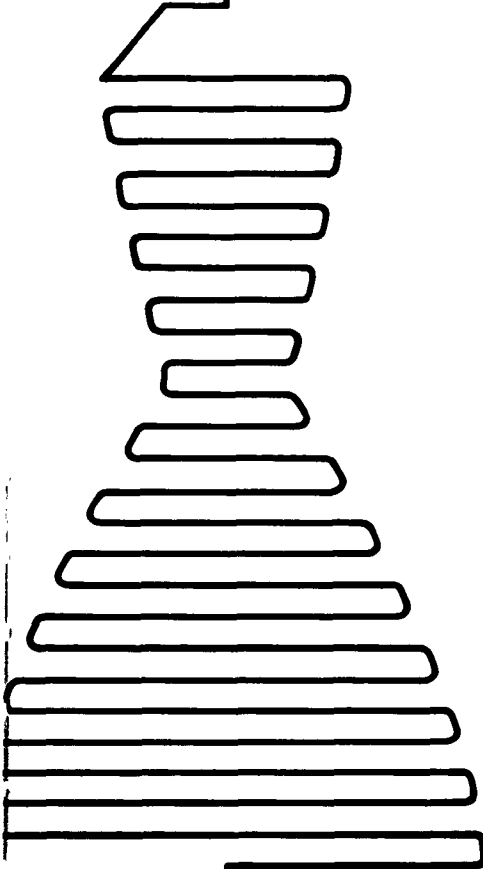
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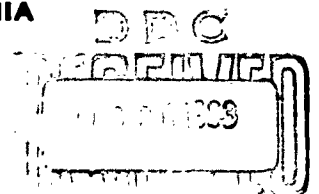
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**ROCKETDYNE**

A DIVISION OF NORTH AMERICAN AVIATION, INC.

CANOGA PARK, CALIFORNIA



R-5297

RETENTION OF RADIATION BOOTS FOR THE  
ATLAS MA-5 PROPULSION SYSTEM

**ROCKETDYNE**

A DIVISION OF NORTH AMERICAN AVIATION, INC.

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Contract AF04(695)-306

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**FOREWORD**

This report was prepared under G.O. 8468 in compliance with Contract AF04(695)-306, Part I, Item 2.b as amended by Request for Service Order SSD 63-05.

**ABSTRACT**

This report presents the studies made in designing, fabricating, and verifying hardware required to improve the radiation boot retention on the MA-5 propulsion system.

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## INTRODUCTION

Difficulties experienced on the E- and F-series Atlas missiles have been attributed to the radiation boot distortion caused by a pressure pulse generated in the flame deflector during initial thrust buildup of the MA-3 booster engine. It was concluded that the pressure pulse was a product of a set of conditions consisting of restricted exhaust gas dispersion as a result of deflector configuration, cold flame deflector environment caused by the dumping of liquid nitrogen and LOX bleeds into the deflector, and a static air mass column in the deflector at engine start. Analysis indicated the magnitude of the pressure pulse was a function of the booster engine thrust buildup rate. A pressure pulse investigation resulted in improvements to the radiation boot retention on the E- and F-series missiles.

It was concluded that the changes proposed for the E- and F-series missiles would offer an increase in reliability for the D-series missiles. A program was therefore initiated to implement similar changes to the D-series, MA-5 propulsion system.

Initially, the pulse criteria for the D-series was not established. The Rocketdyne program was based on the pulse criteria (5 psi) used on the E- and F-series missiles. Later in the program it was indicated that a pulse criteria of 2.5 psi should be used on the D-series missiles.

This report presents the studies made and the resultant recommendations to improve the radiation boot retention on the MA-5 propulsion system.

**SUMMARY**

The program consisted of designing, fabricating, and verifying hardware required to improve the radiation boot retention on the MA-5 booster, the standard D-series sustainer and the standard launch vehicle (SLV-3) sustainer.

The booster program consisted of verifying the adaptability and suitability of utilizing the segmented channels used on the MA-3 booster engines as proposed by engineering change proposal (ECP) MA3-345.

The standard D-series sustainer program consisted of designing, fabricating, and verifying hardware to: (1) increase the height and quantity of radiation boot retention clips, and (2) lower the profile of the four drain lines to minimize the gap between the boot and the aspirator.

The SLV-3 program consisted of studies to minimize the gap between the radiation boot and the aspirator caused by the addition of the one-inch lube drain line added to the SLV-3 sustainer by ECP MA5-65.

Considerable effort was expended during this program to establish the design criteria. The pulse criteria has been established at 2.5 psi.



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**CONCLUSIONS AND RECOMMENDATIONS**

**Booster**

The addition of segmented channels on the third thrust chamber ring will provide a positive means of retaining the booster radiation boot. The change was accomplished by ECP MA5-90.

**D-Series Sustainer**

More positive sustainer boot retention is provided by increasing the height and number of the sustainer boot retention clips and lowering the profile of the four drain lines. The engine changes required are proposed by ECP MA5-91. It is recommended that General Dynamics/Astronautics (GD/A) increase the strength of the retention spring rate to 17 lb/in. and an 84-pound preload.

**Sustainer, SLV-3**

More positive boot retention can be provided on the SLV-3 by increasing the height of the three aspirator clips in the area of the turbine exhaust duct. To minimize the gap between the radiation boot and the aspirator caused by the one-inch diameter lube drain line, it is recommended that GD/A add tufting to the boot. The addition of a tunnel over the drain lines is not recommended.

**RETENTION OF RADIATION BOOTS FOR THE  
ATLAS MA-5 PROPULSION SYSTEM**

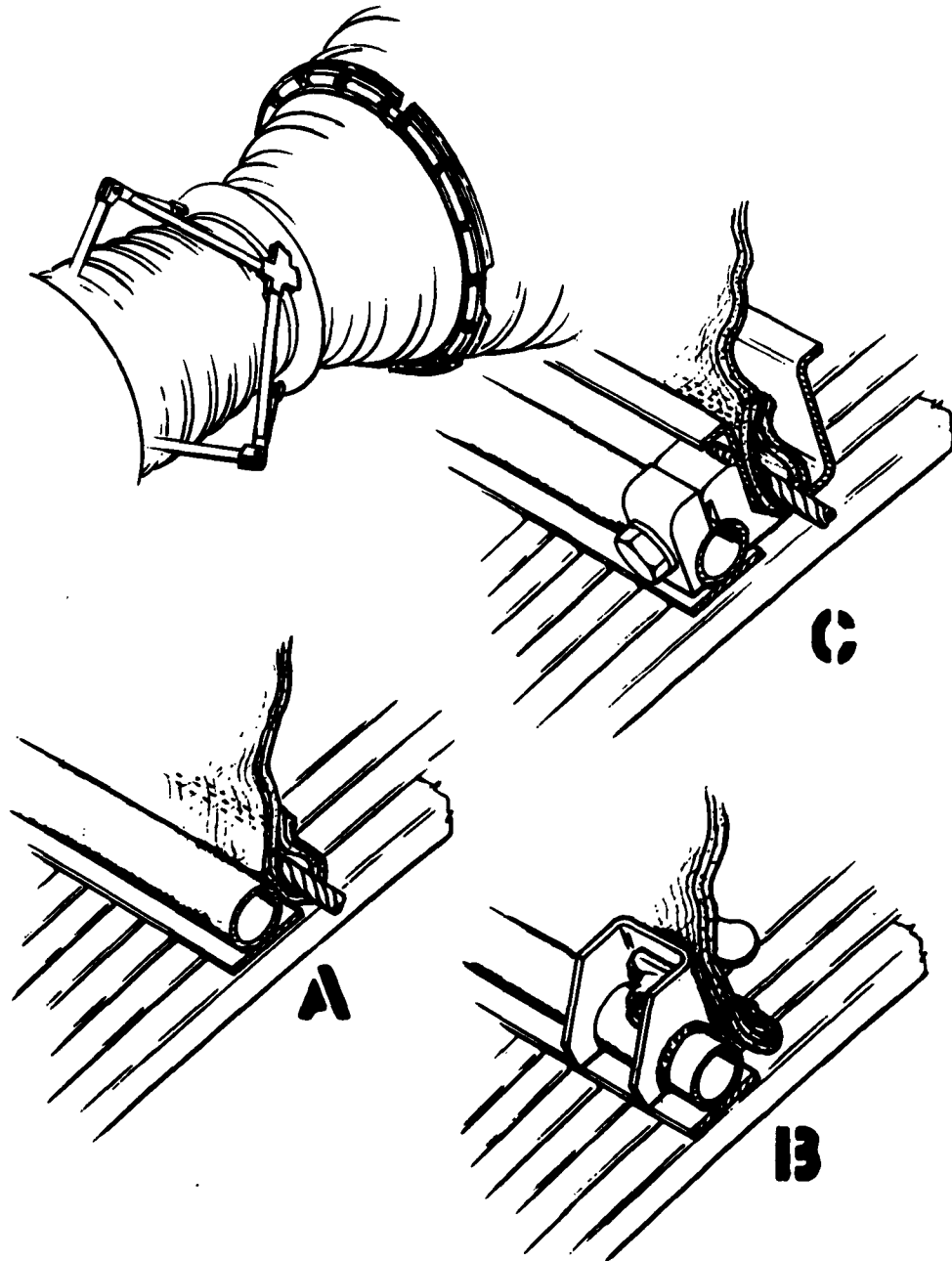
**BOOSTER RADIATION BOOT RETENTION**

The booster radiation boot on the D-series missiles was retained by means of a cable to the third thrust chamber ring (Fig. 1A). A more positive means of retention was desired. Two methods of attachment were considered: Camloc fasteners (Fig. 1B) and a segmented channel and cable (Fig. 1C). Because the Camloc fastener method would necessitate a new radiation boot and welding on the chamber, this method was abandoned.

The segmented channels were added to the E-series missiles per ECP MA3-345. The most expedient method of providing positive boot retention was to utilize the segmented channels used on the MA-3 propulsion system. A program was initiated to verify the adaptability and the suitability of using the MA-3 channels on the MA-5 propulsion system. The program consisted of (1) reviewing the MA-3 analysis, (2) reviewing the MA-3 engine testing, (3) cold gimbaling tests on missile 75F, and (4) missile installation verification.

**Analysis**

The design requirements established for retaining the boot on the booster engine was to provide a mechanical means for attaching the boot to the booster engine in such a manner that the boot is retained in both the forward and aft directions. Two methods were investigated: the Camloc fasteners and the channels. In each case, the load path was from



**Figure 1 . Booster Radiation Boot Retention Methods**

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the boot through the reinforcing ring and into the thrust chamber. The reinforcing ring on the chamber was tested and found capable of resisting a load of 500 lb/in. The Camloc fastener brackets failed at a load of 500 lb/in, which is 20 times the design load of 2.5 psi (Fig. 2 and 3).

The channels were analyzed (Appendix A) and tested as indicated in Fig. 3 ; the load was applied in the forward direction and a maximum rotation of 3.16 degrees occurred at the free end at approximately six times the design load.

**Engine Testing**

No engine testing of the segmented channels was accomplished on the MA-5 propulsion system. The segmented channels were installed on MA-3 boosters 1121-2, 1218-3, 1113-3 and 1217-3, with a simulated missile boattail at Alfa-1. The tests are listed in Table 1 . No detrimental effects or conditions were noted throughout the testing.

Segmented channels were installed on missile 75F at Sycamore Canyon test site. The testing with channels installed consisted of eight tests on booster No. 1 and seven on booster No. 2. These tests are tabulated in Table 2 .

**Cold Gimbaling Tests**

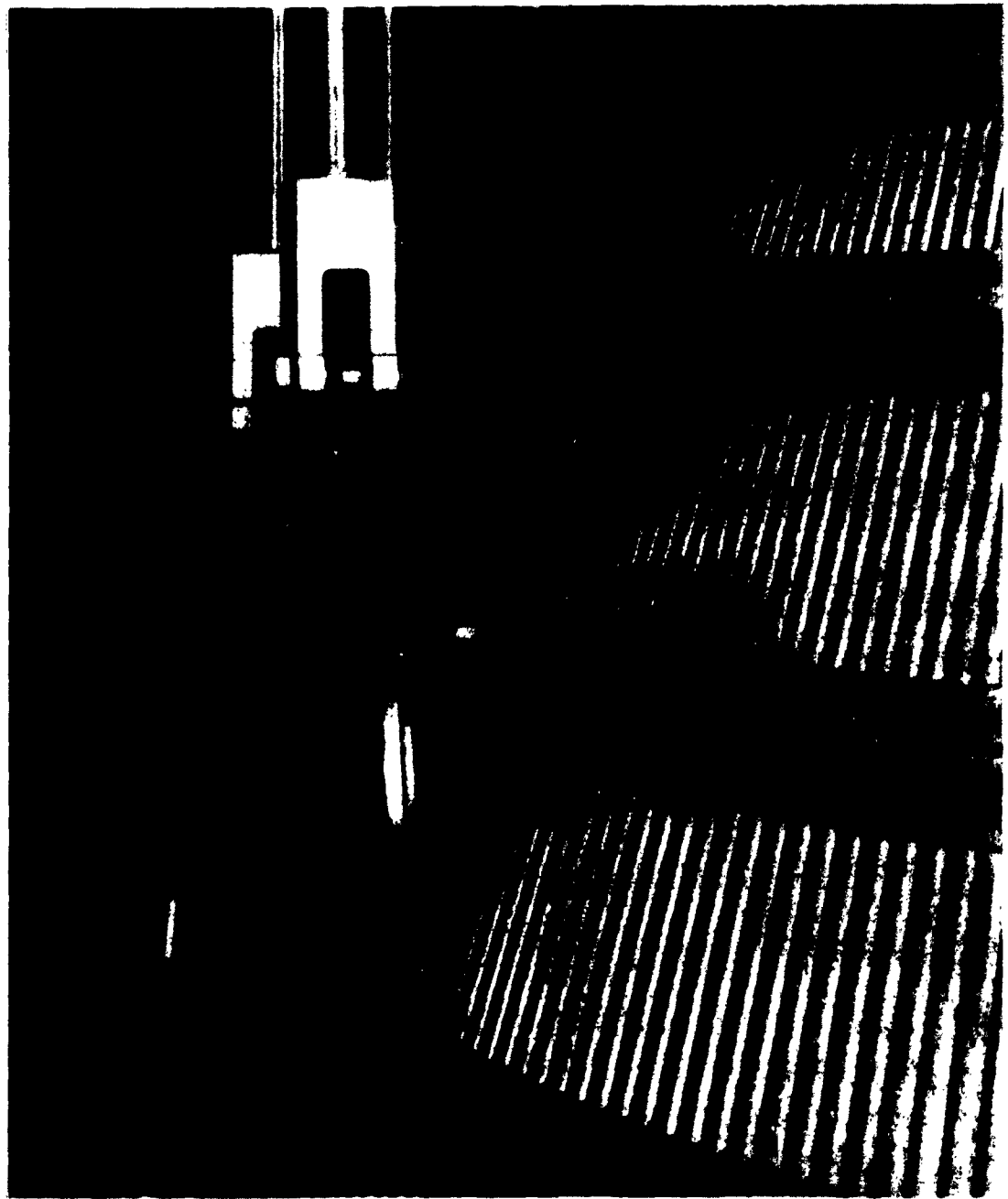
On 17 May 1963, a series of cold gimbal tests were performed on the booster engines of missiles 75F at the GD/A Sycamore Canyon test facility. Booster engine radiation boot segmented channels (per ECP MA3-345) were installed on the No. 1 booster engine of missile 75F prior to test 609-B12, and on



1BK34-1/21/63-C1B

**Figure 2 . Camloc Fastener Tests**

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1BK34-2/21/63-C1B

Figure 3 . Channel Tests

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**TABLE 1**

**MA-3 BOOSTER TESTING**

<b>Short Tests</b>			
<b>Engine No.</b>	<b>No. of Tests</b>	<b>Accumulated Time, seconds</b>	<b>Test No.</b>
1121-2	46	90	512-076 through 122
1218-3	14	28	512-112 through 125
<b>Totals</b>	<b>60</b>	<b>118</b>	
<b>Long Tests</b>			
<b>Engine No.</b>	<b>No. of Tests</b>	<b>Accumulated Time, seconds</b>	<b>Test No.</b>
1113-3 (B <sub>2</sub> )	49	4025	512-131 through 193
1217-3 (B <sub>1</sub> )	4	340	512-194 through 197
<b>Totals</b>	<b>53</b>	<b>4365</b>	

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TABLE 2

MISSILE 75F TESTING

Test No.	Date, 1963	Duration, seconds	Booster No. 1	Booster No. 2
S2-609-B12	5 April	5	Segmented Channel	Camloc
S2-610-B13	13 April	5	Segmented Channel	Segmented Channel
S2-611-B14	30 April	5	Segmented Channel	Segmented Channel
S2-612-B15	14 May	5	Segmented Channel	Segmented Channel
Gimbal Test	17 May			
S2-613-B16	28 May	6	Segmented Channel	Segmented Channel
S2-614-B18	7 June	8	Segmented Channel	Segmented Channel
S2-615-B19	25 June	10	Segmented Channel	Segmented Channel



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the No. 2 booster engine prior to test 610-B13. Four hot firings had been accomplished since the first channel installation.

Prior to initiating the gimbal tests, a visual inspection of the channel installation and thrust chambers in the area of the channels was performed. No thrust chamber or channel discrepancies were noted. Safety wire was removed and an as-found torque check was performed on the channel attach bolts. The as-found torque values are listed in Table 3. All bolts were retorqued to 190 in.-lb. The end bolts of each channel were then safety wired.

Both booster engines were gimbaled at the following frequencies: 3, 5, 7, 9, and 11 cps; first in pitch, then in yaw. Excursion was 0.5 degree; duration at each frequency was 3 seconds. The above procedure was accomplished five times. The channels and boots were observed during the test.

Posttest hardware inspection and torque checks were performed. Posttest inspection revealed no damage or other discrepancies resulting from these tests.

1. There was no evidence of structural damage at or near the second thrust chamber stiffening ring where the channels are attached to the chamber.
2. There was no indication of relative movement between the thrust chambers and the channels.
3. There was no thrust chamber damage.
4. There was no significant torque change.

The posttest results of the torque checks are presented in Table 3.

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TABLE 3

TORQUE VALUES

Bolt No.*	As Found		Posttest	
	Booster No. 1, in.-lb	Booster No. 2, in.-lb	Booster No. 1, in.-lb	Booster No. 2, in.-lb
1	160	140	180	190
2	180	40	190	190
3	200	110	180	190
4	110	180	180	190
5	120	190	180	200
6	160	180	180	190
7	100	160	180	190
8	140	190	180	190
9	180	160	190	190
10	180	160	190	180
11	280	220	190	190
12	160	160	190	190
13	170	145	190	190
14	180	140	190	190
15	180	280	180	190
16	180	200	180	190
17	180	190	190	190
18	160	140	180	190

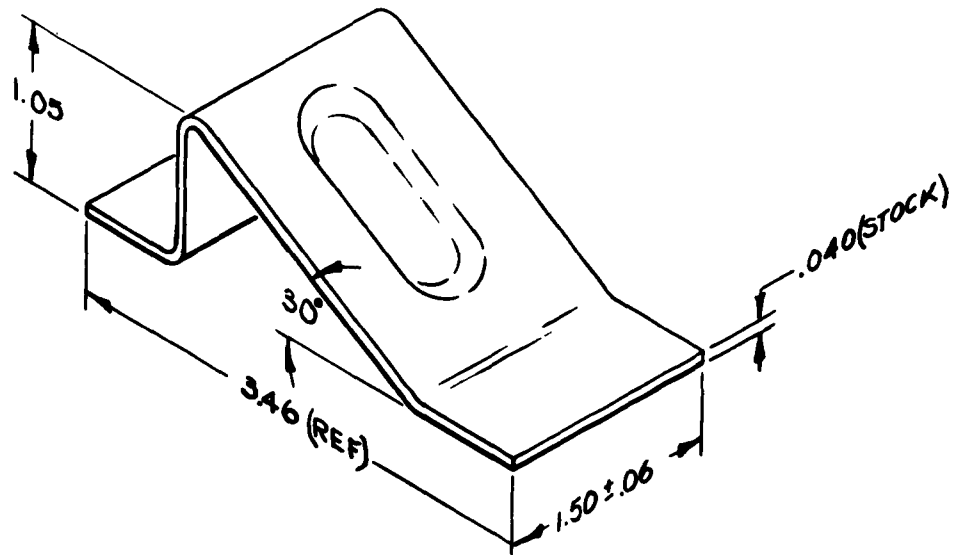
\*Clockwise from S-4 side

### Mockup Verification

A set of channels and a radiation boot were installed on a missile at GD/A on 2 May 1963. The installation was satisfactory.

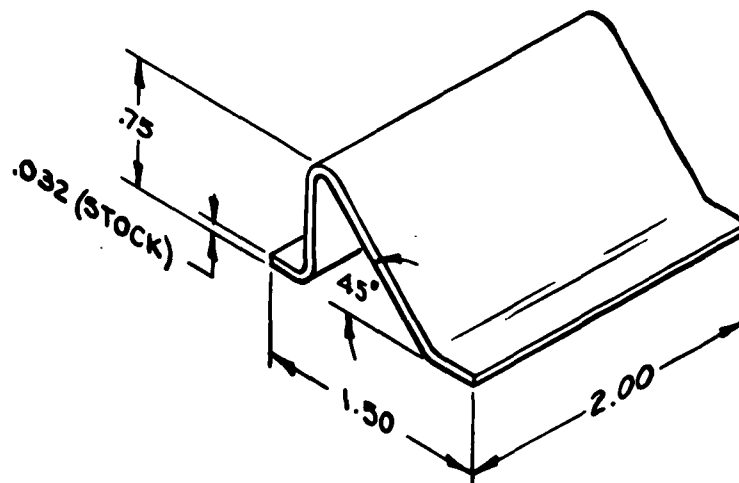
### SUSTAINER STANDARD D-SERIES RADIATION BOOT RETENTION

The radiation boot on the standard D-series sustainer is held by a spring in the radiation boot, and the boot's forward restraint is provided by clips on the sustainer turbine exhaust aspirator. The engine restraint consisted of 19 clips that were 0.032 inch thick, 0.75 inch in height, and were resistance-welded to the aspirator (Fig. 4 ). The GD/A spring rate was 1.12 lb/in. with a 47-pound preload. Although the MA-5 propulsion system did not experience any failures attributed to the sustainer radiation boot, an improvement in boot retention was desired. The improvements consisted of increasing the height, number, and strength of the aspirator clips, lowering the profile of the small drain lines and increasing the strength of the retention spring (Fig. 4 and 5 ). The detail design could not be implemented because the design criteria was not firmly established. The MA-3 propulsion system boot retention was based on a 5-psi pressure pulse, and it was Rocketdyne's desire to use the same criteria on the MA-5, although the MA-5 propulsion system does not encounter this high pulse. Analysis showed that the MA-3 propulsion system would have a safety factor of 1.49 using reinforced aspirator clips and a spring with a spring rate of 17 lb/in. and an 84-pound preload. The MA-5 safety factor was 1.35 because of the GD/A imposed limit of 1.05 inches for the height of the clips vs 1.75 on the MA-3 propulsion system. To provide a 1.5 factor of safety on the MA-5, it would be necessary to reinforce the clips by gussets and increase the spring preload to 130 pounds. It was decided that 5 psi was an unrealistic limit for the MA-5 and that 2.5 psi should be used. Using 2.5 psi, the safety factor is 1.9 for the MA-5 propulsion system.



**I**

## PROPOSED CONFIGURATION



## EXISTING CONFIGURATION

Figure 4 . Sustainer Boot Retention Clip

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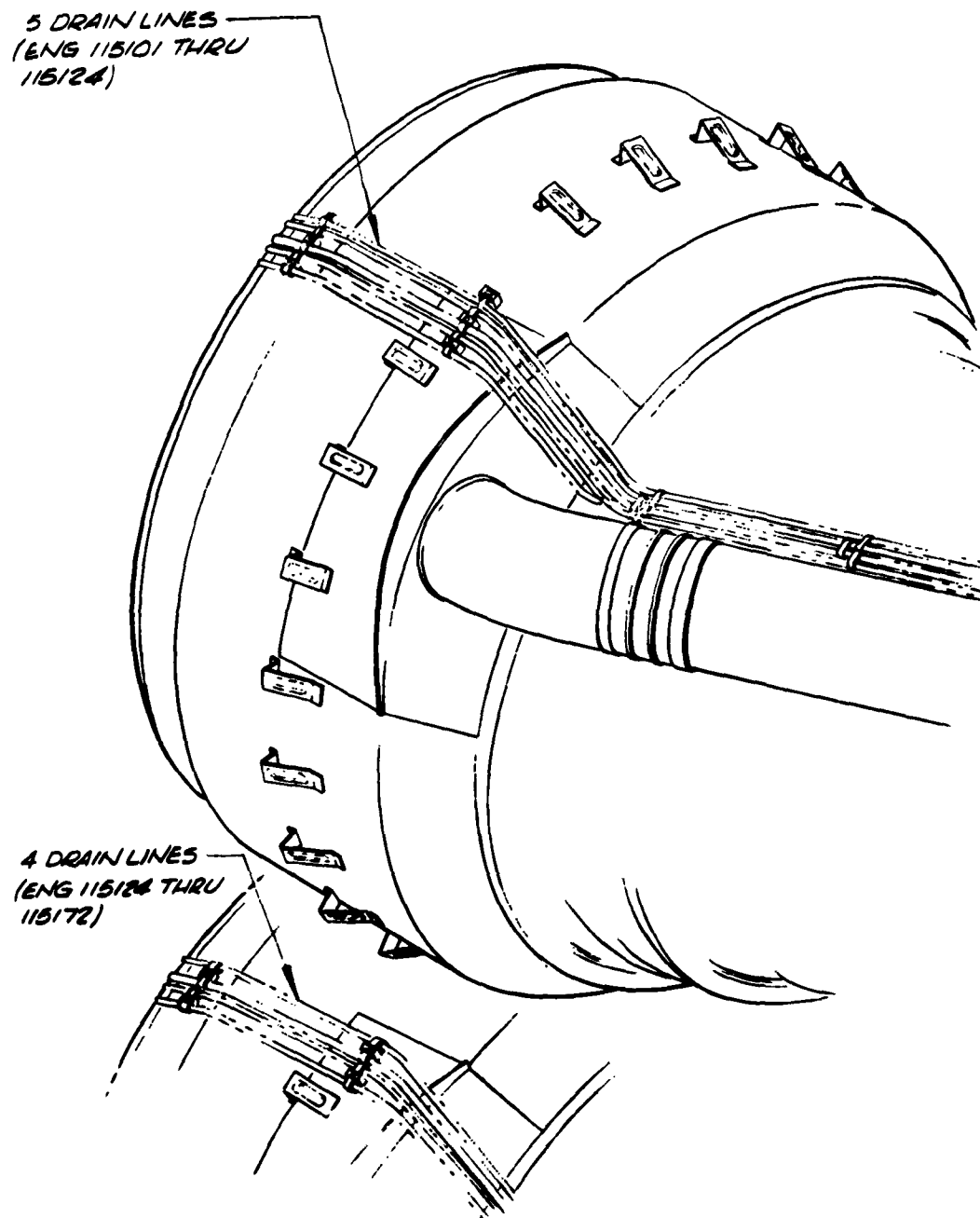


Figure 5 . Improvements to Radiation Boot Retention

The program to verify the configuration consisted of: (1) analysis of the spring and clip, (2) mockup verification, and (3) engine testing.

### Analysis

The design requirements established for the sustainer boot are: (1) the boot should be able to resist a 2.5-psi pressure pulse and not slip over the aspirator clips, and (2) the boot should be able to move in the aft direction during booster separation.

An analysis (Appendix B ) was made to determine the spring requirements necessary to resist the 2.5-psi design pressure acting on the boot in the forward direction. Using the spring with an 84-pound preload and a spring rate of 17 lb/in., the factor of safety is approximately 1.9.

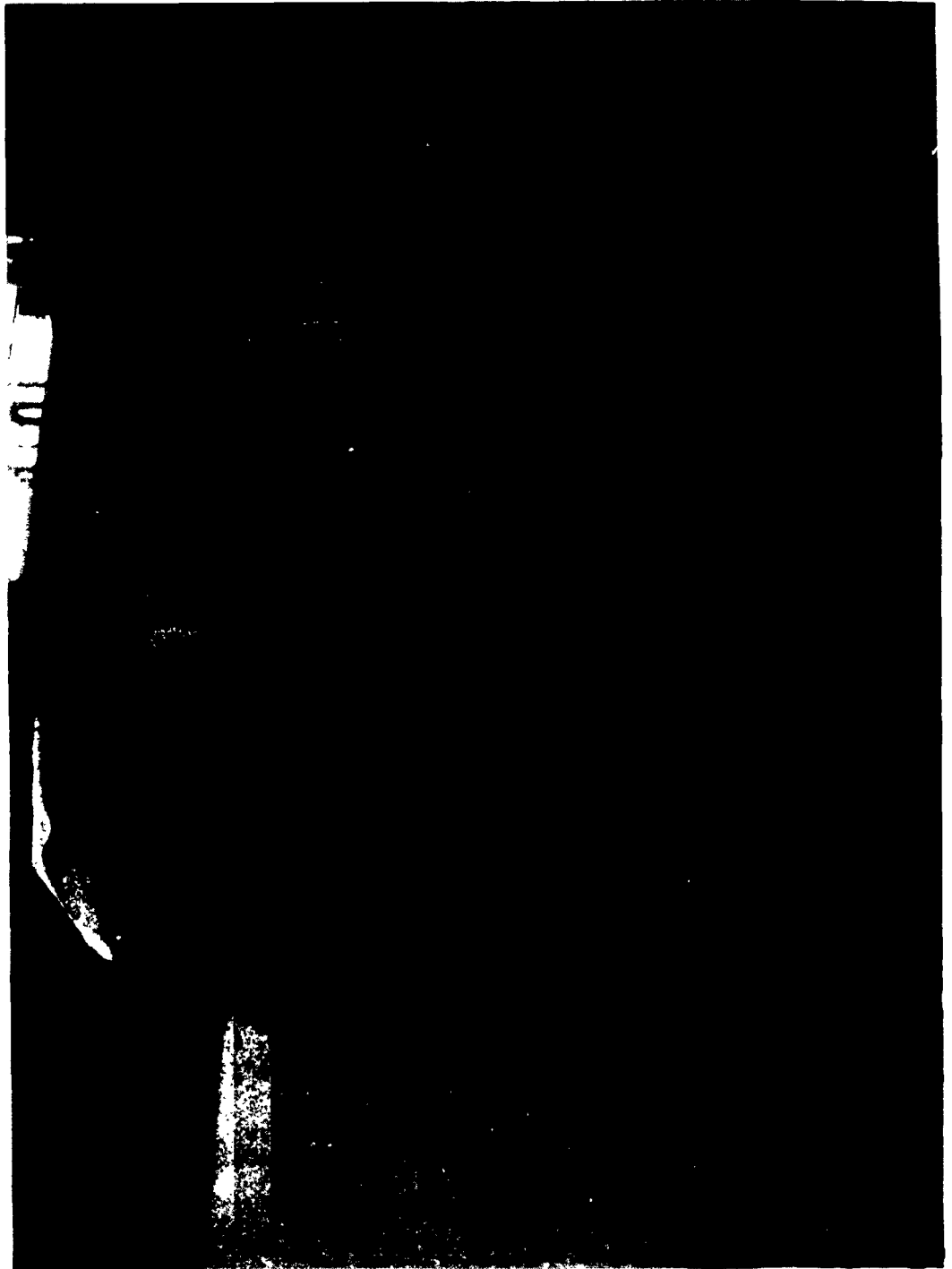
A test utilizing the sustainer boot with the (84-pound preload and a spring rate of 5.4 lb/in.) spring was set up and loaded in the forward direction to determine the actual load required to pull the boot over the clips (Fig. 6 ). The minimum load pulled over the clips by the boot was 60% of the design load.

A structural test was performed on the MA-3 sustainer to determine the structural capability of the chamber assembly with respect to a load applied at 14 degrees to the centerline of the thrust chamber and distributed around the aspirator (Fig 7 ). The maximum actuator load, 1300 pounds, occurred when a 3/16-inch AN cable was pulled off the aspirator. No damage was incurred to the chamber or aspirator.



1BL34-5/3/63-C1F

Figure 6 . Sustainer Boot Load Test



1BL34-3/1/63-C1

Figure 7 . MA-3 Sustainer Cable Slipping Test



The clip was tested to determine the load at which yielding occurs and at what load ultimate failure would occur. The design load for each clip is 160 pounds in the forward direction. There was no visible deformation of the clip at 320 pounds; the clip was loaded to 1100 pounds without collapsing, although the aft leg was completely deformed and the load was being carried in tension (Fig. 8 ).

#### Mockup Verification

R&D engine 5501 was modified to add the aspirator clips and the lower profile drain lines. On 9 July 1963 a radiation boot, using a spring with a spring rate of 17 lb/in. was installed on this engine at PFL. The installation (Fig 9 through 11 ) was considered satisfactory.

#### Engine Testing

A R&D engine with the proposed clips was tested three times for an accumulated time of 689.2 seconds. After the engine tests, the aspirator was visually inspected and a dye penetrant inspection of the clip welds was made. No defects or discrepancies were noted. The engine testing is tabulated in Table 4 .



1BD35-7/11/63-C1C

Figure 8 . Sustainer Boot Retention Clip Test



1B033-7/9/63-SLA

Figure 9 . Mockup Verification



1B033-7/9/63-SLB

Figure 10 . Mockup Verification



LB033-7/9/63-SIC

Figure 11. Mockup Verification

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TABLE 4

ENGINE TESTING OF RETENTION CLIPS

Test No.	Date, 1963	Duration, seconds
515-061	9 July	292.0
515-062	11 July	77.2
515-063	12 July	<u>320.0</u>
Total		689.2

### SUSTAINER SLV-3

The SLV-3 sustainer engine was modified by ECP MA5-71 to provide new aspirator clips and lower profile drain lines, and by ECP MA5-65 to route the lube drain line into the aspirator. New clips of 1.05 inches height (Fig. 4) were added per ECP MA5-71, and further improvement could be made by increasing the height of the three clips in the area of the turbine exhaust hump. Studies were initiated to determine methods of minimizing the gap between the radiation boot and the aspirator caused by the drain lines. On the standard D-series missiles the drain lines were small diameters, 0.5 and 0.25 inch; the radiation boot filled the small gaps around the tubes. The SLV-3 has an additional one-inch-diameter drain line which caused a gap to exist between the radiation boot and the aspirator. The addition of a tunnel or covering around the lines was studied.

Two tunnel configurations were designed and fabricated (Fig. 12), one was fabricated of fiberglass and the second with 321 stainless steel. The fiberglass configuration was discarded because its structural integrity is very questionable at temperatures higher than 500 F. The metal tunnel will adequately perform the function of eliminating the gap, but would require further evaluation beyond the scope of this program. Engine testing would be required to determine the adequacy of the tunnel support and to verify that the tunnel would not cause any deleterious effects to the engine or aspirator.

The gap could be minimized quite easily by providing tufting (additional boot material) in the area of the drain lines (Fig. 10).

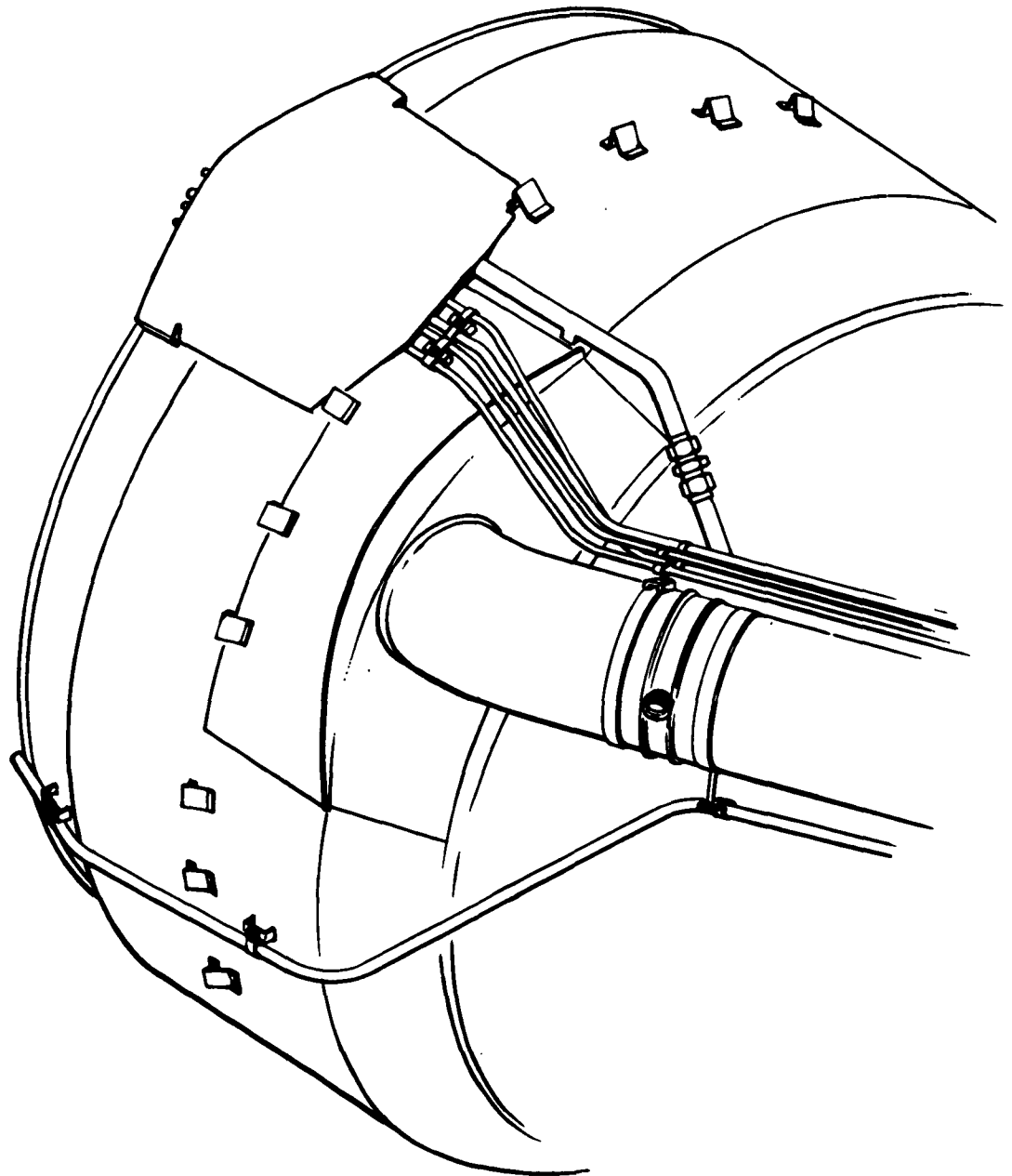


Figure 12 . Tunnel Configuration



APPENDIX A

CHANNEL ANALYSIS

ASSUMPTION

The load will be reacted as a couple between the reinforcing ring and the clamp bearing on the band.

ANALYSIS

$W_f$  - The load in the forward direction (50 lb/in.)

$W_a$  - The load in the aft direction (40 lb/in.)

$P_c$  - Load per clamp

$P_{cf} = 16.8 \cdot \frac{22 \text{ degrees}}{57.3} W = 323.5 \text{ pounds forward}$

$P_{ca} = 258 \text{ pounds aft}$

$P_f = \frac{323.5 \times 1.47}{0.8} = 594 \text{ pounds (Fig. 13)}$

$P_a = \frac{258 \times 1.47}{0.75} = 507 \text{ pounds (Fig. 13)}$

Shear and bending on bolt due to load acting in forward direction.

$P_s = 594 \times \cosine 21 \text{ degrees} = 566 \text{ pounds shear load}$

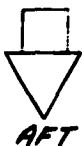
$M_b = 566 \times 0.3 = 170 \text{ in./lb bending moment}$

$\sigma_s = 7000 \text{ psi shear stress bolt}$

$\sigma_b = 51,000 \text{ psi bending stress bolt}$

$\sigma_t = \text{Stress due to bolt preload (32,200 psi)}$

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**Figure 13. Channel Reference Drawing**

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$$\sigma_T = 51,000 + 32,200 = 83,200 \text{ psi}$$

$$\text{F.S.} = \frac{140,000}{83,200} = 1.69$$

Shear and bending on bolt due to load in the aft direction.

$$P_s' = 478 \text{ pounds}$$

$$M_b' = 143 \text{ in./lb}$$

$$\sigma_s' = 5930 \text{ psi}$$

$$\sigma_b' = 42,800 \text{ psi}$$

Bolt tensile load due to P

$$P_b = \frac{258 \times 1.5}{0.65} = 596 \text{ pounds}$$

$$P = P_o + kP_b$$

$$P_o = \text{Initial preload (-2600 pounds)}$$

$$k = \text{Combined spring rates of bolt and clamp (0.613)}$$

$$P = 2600 + 0.613 (596) = 2966 \text{ pounds}$$

$$\sigma_t' = \frac{2966}{0.0809} + 42,800 = 79,600 \text{ psi}$$

$$\text{F.S.} = \frac{140,000}{79,600} = 1.76$$

APPENDIX B

**SUSTAINER BOOT ANALYSIS**

**ASSUMPTIONS**

1. Radius of boot determined with the thrust chamber in the neutral position ( $R_b = 10$  inches).
2. Design pressure  $\Delta_p = 2.5$  psi.
3. The curve of the spring between clips in the longitudinal direction is a parabola.

**ANALYSIS**

- $P_o$  = Preload of spring (84 pounds)
- $k$  = Spring rate (17 lb/in.)
- $L$  = Total length of spring (154 inches)
- $l$  = Length of spring between tangent points
- $\Delta_t$  = Change in length of spring due to radial growth
- $N_\theta$  = Membrane load in boot (25 lb/in.)
- $P_s = P_o + \Delta_t \frac{L}{l} k$  Load in spring due to preload and radial growth of spring.
- $e$  = Clip height (1.01 inches)
- $a$  = Distance between clips (6.42 inches)

Increase in spring load due to  $N_{\theta}$  acting over three clips (Fig. 14)

$$\begin{aligned}\Delta_t &= 2 (\Delta_a + \Delta_b) = 0.8463 \\ l &= 26.7 \text{ inches} \\ P_s &= P_o + \Delta_t \left(\frac{L}{l}\right) k \quad (\text{Eq. 1}) \\ P_s &= 84 + 0.8463 (5.77)(17) = 84 + 83 = 167 \text{ pounds}\end{aligned}$$

The total load reacting the radial load at each clip (Fig. 15) is developed by ( $T_s$ )

$$T_s = P_s + \Delta_s \frac{L}{6.42} k \quad (\text{Eq. 2})$$

$\Delta_s$  = Increase in spring length due to the curve of spring between clips.

$$\Delta_s = \frac{N_{\theta}^2 \cdot d^3}{24 \cdot T_s^2}$$

Substituting for  $\Delta_s$  in Eq. 2,

$$T_s^2 (T_s - P_s) = N_{\theta}^2 d^3 k$$

$d$  = Distance between clips (4.92 inches)

$$\begin{aligned}T_s^2 (T_s - 167) &= 1,265,000 \\ T_s &= 198.96 \text{ pounds}\end{aligned}$$

$Q$  = Radial load developed inward due to  $T_s$  (for three clips)

$$Q = \frac{198.96 \text{ pounds}}{2.73} = 72.8 \text{ pounds/clips}$$

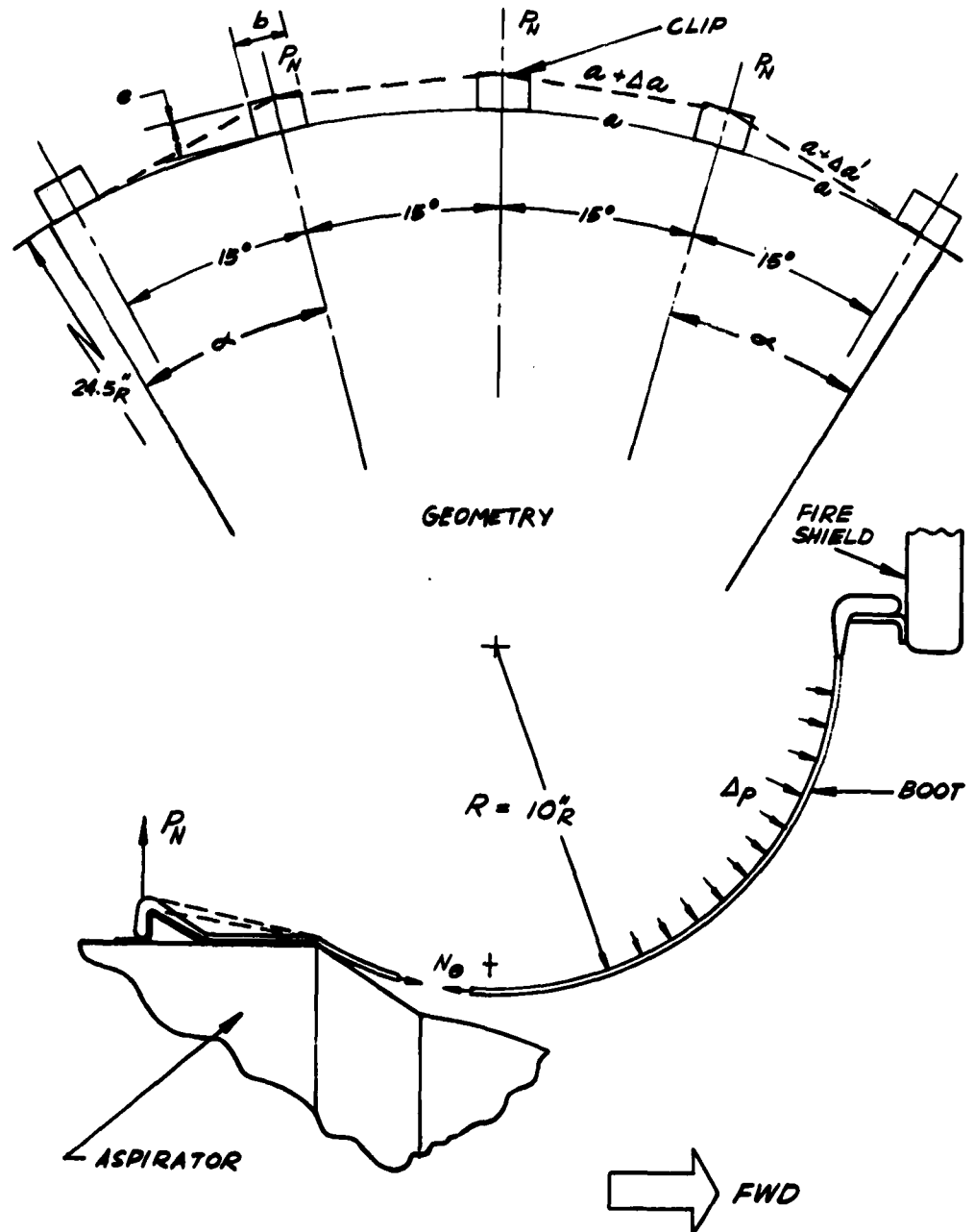
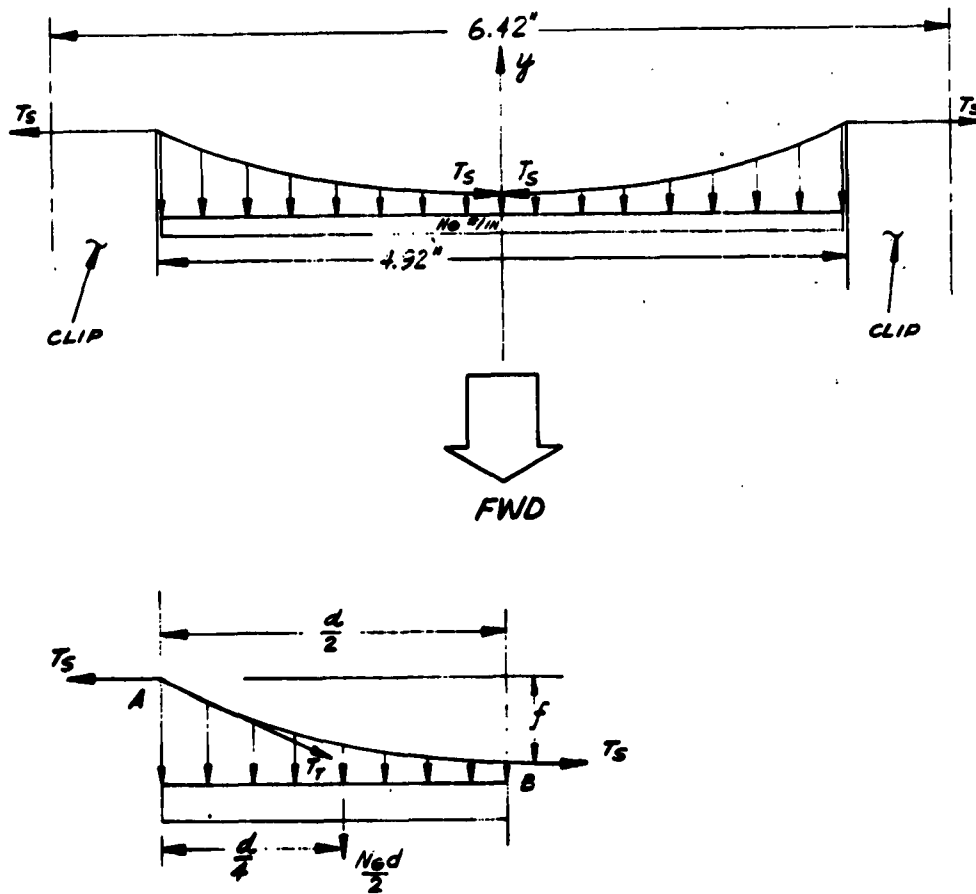


Figure 14. Membrane Load vs Pulse Pressure



Due to membrane load  $N_0$  that is distributed in the longitudinal direction, the curve assumed by the spring is a parabola.

**Figure 15 . Membrane Load in Spring Caused By Pressure Pulse**

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$P_n$  = Radial load developed by 2.5-psi pressure (37.5 pounds)

$$F.S. = \frac{Q}{P_n} = \frac{72.8}{37.5} = 1.94$$